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State of the non-operations based research of hard shoulder running

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Abstract

Hard Shoulder Running (HSR) is an operationally focused active traffic management strategy to optimize the utilization of the roadway, specifically the shoulder portion of the roadway geometry. Roadway networks needs to be more sustainable by utilizing its full capacity before using more materials to construct an expanded roadway. The understanding of the operational benefits has been the focus of much HSR research as it is an operational focused Active Traffic Management (ATM) strategy. Before HSR can be utilized, its effects on safety and the pavement structure on the shoulder need to be understood. While it has been found to improve the road operation, it must be safe and structurally sound. This paper provides a literature review of the HSR research that analyzed the safety effects and the pavement performance effects. HSR is a quality strategy that can reduce congestion, car emissions, and paved lane use requirements through improved traffic flow.

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Keywords: Hard Shoulder Running; Active Traffic Management; Sustainable Roadway Network; Safety Performance; Shoulder Pavement Performance

1. Introduction

Hard Shoulder Running (HSR) is the utilization of the shoulder of a roadway during high congestion periods and provides a temporary roadway capacity increase during the time period where there is need. This strategy is part of

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the Active Traffic Management (ATM) approach being recommended by the Federal Highway Administration (FHWA). HSR focuses on improving the operational efficiency of the roadway, hence the main research emphasis surrounding the topic is based upon operational benefits. The issue with this process is that there are other major factors to account for before fully understanding the implementation benefits of HSR. Two major factors to account for are the safety effects and the pavement effects. Each has major impacts on the utility of this strategy. Accounting for both aspects in addition to the operational benefits will provide a more sustainable roadway network.

1.1. Safety Effects Background

Safety is a significant aspect to account for in analyzing a new operation-based strategy. Besides operational benefits, safety benefits were the next most researched benefits as they are the most noticeable roadway aspect to be effected by HSR. While many drivers desire to get to their destination on-time, they also want to be able to arrive safely, as well. HSR removes the shoulder for major traffic periods of the day but this eliminates a continuous refuge area for vehicles that breakdown. This also removes the travel lane for emergency vehicles trying to reach a crash. The safety of a roadway can be estimated but the performance of the roadways is determined by the drivers utilizing the roadway. The benefits must analyze two parts of safety: if there is a higher inclination towards accidents and are their more accidents occurring on the roadways during HSR? The inclination towards accidents is to determine if the change in the geometry of lanes on the roadway negatively affect the safety. While there is a harmful effect for having a small or no shoulder, research needs to understand if the additional lane provides safety benefit to counterbalance the minimal shoulder effect. If this strategy negatively affects the concept of the roadway in the design process then the strategy may need an alteration to minimize the effects. The second aspect of safety that needs analysis is if the safety is negatively affecting the roadway once HSR is implemented. This research focus will improve upon the HSR strategy based upon possible flaws that may not have been accounted for within the initial design for this strategy.

1.2. Pavement Performance Effects Background

Pavement performance, while it affects operations and safety, is a distinct aspect of transportation that tends to have distance from the two other aspects. Pavement performance is a significant influence for the implementation of HSR. Any additional loading on a portion of a roadway will negatively affect the pavement performance. In the safety scenario, the shoulder is designed the same as the mainline lanes as the implementation of HSR could possibly improve the roadway performance. The use of HSR will distribute a major loading period on the roadway better than previously. For example, for a two lane roadway the split of the loading is roughly 50-50 and with HSR this roadway could be a loading split of roughly 33-33-33. The additional lane could possibly reduce the loading on a lane during high congestion by about 34% with that logic. Some operational based studies have found the split for a three lane HSR structure would be closer to a 40-40-20 split which would still provide a 20% loading reduction in the mainline lanes during high congestion [1]. This thought process is in the safest scenario as the shoulder pavement design is the same as the mainline lanes, also known as full depth shoulders. In fact, many states in the United States (US) are just beginning to switch to full depth shoulders, such as New Jersey, while others have varied shoulder design methods, such as Florida or Washington State [2, 3, 4]. The shoulder designs of these states are based upon a minimum cross section or a percentage of the truck traffic on the roadway [2, 3, 4]. These pavement cross section designs are minimal compared to the mainline lanes and the implementation of HSR could negatively affect the shoulder pavement performance greatly depending on the design. If the pavement degrades rapidly then the benefit of HSR can be offset as major rehabilitation will be required to repair the damage. For proper implementation of HSR, the effects of the shoulder designs on the pavement performance needs to be understood

1.3. Objectives

This paper is to review the current status of research of non-operational effects of HSR, specifically safety and pavement performance effect. The objective of this review paper is to identify the areas of strength along with the areas of improvement in current research that aims to account for the effects of HSR.

2. Literature Review

This paper includes a selection of research that focuses on the safety and pavement performance effects of HSR. While other studies have either mentioned or touched on these topics, the studies included below comprise of those that focused mainly or entirely on the topics. If other non-operational, such as environmental impacts, of HSR are included within a study these will be discussed as well.

2.1. Implementing Active Traffic Management Strategies in the U.S. [5]

This research study was one of the largest studies found on the topic of HSR that included emphasis on non-operational effects. The focus of the paper overall was on ATM including HSR, or temporary shoulder use, the terminology used by the study. The specific region analyzed was roughly a nine mile segment of Interstate 65 in Birmingham, Alabama. The study examined the feasibility of HSR in the area and aimed to help expand the knowledge of HSR to provide guidance for future use in the US. The seven scenarios analyzed by the study were no shoulder use, left shoulder HSR, peak period left shoulder HSR, right shoulder HSR, no shoulder use with an incident, one hour of left shoulder HSR with an incident, and two hour left shoulder HSR with an incident. The incident HSR scenarios included HSR downstream of the incident. Microscopic simulation software called CORSIM was utilized for the modeling process. This system is stochastic, allowing for variable scenarios for enhanced realism. The software provides a spectrum of operational outputs but also includes environmental emissions from fuel usage.

The initial environmental data was evaluated with six vehicle types from passenger cars to buses. The hydrocarbon (HC) emissions of each vehicle type were compared across each scenario and average of the vehicle types across each scenario. The results found that left shoulder HSR reduced the HC emissions by 10-13%. The right shoulder HSR indicated some HC reduction but on average was minimal. With an incident occurring, the HC emissions rose when there was no HSR use. Under the one hour HSR with an incident scenario, the HC emission reduced to the emission levels of the base no HSR scenario with no incident as the additional lane offset the loss of a lane due to the incident. The two hour HSR with an incident scenario reduced HC emissions further but only by about 7% on average across all vehicle types.

From the analysis the results were quantified and analyzed through a cost-benefit analysis. The cost information was provided through various sources including the National Safety Council for estimated crash costs and the US Environmental Protection Agency for emission costs. The study stated to be using a life-cycle cost to estimate the benefits and costs. The data is presented in a table summarizing the benefits of the different scenarios indicating higher or the same crash costs for the HSR scenarios when compared to the no HSR scenarios. The emission costs for the HSR scenarios are presented to be lower or the same as the base scenarios of no HSR in the same table. When describing the results, the study states both the crash costs and emission costs are lower by various amounts across the different scenarios with HSR.

This study touches upon the safety and environmental impacts of HSR. The environmental impacts were evaluated further as it was an output of the modeling software. The findings indicate a reduction in emissions with the use of HSR. The cost benefit analysis of this study indicates benefits of HSR on both aspects in some manner but does not fully explain the depth of the benefits. The paper focuses mainly on the operational benefits. The data is collected to analyze the safety and environmental impacts of HSR are a positive of this research but no future research was found on the topic from these authors. The major findings from this is the environmental benefit of HSR. One environmental benefit of HSR especially is the analysis indicating that HSR could possibly remove the emission increase or further improve the emissions surrounding a crash on the roadway.

2.2. Hard Shoulder Running as a Short-Term Measure to Reduce Congestion [6]

The title indicates an emphasis on operational effects but the initial focus of the study is a safety analysis with an operational investigation to strengthen the findings. This roadways used in this study are the Germany roadways, Freeway A4, A6, and A7. The study collected crash reports and if possible a copy of the original crash report from the police to provide in-depth knowledge of each crash. It should be noted that the HSR system in this study is opened once the traffic reaches a specific traffic volume and not set hours. The results were analyzed by two crash rate types: group 1 includes severe injuries through fatalities while group 2 focuses on the opposite with lower severities down to property damage only (PDO). The conclusions of the paper were that HSR safety effects can be variable though they tend to performance at the same safety level and possibly slightly safer. A few anomalies with this conclusion were found to be high risk areas marked by the police and did behave consistently for reliable results. It found that areas with typically safer sections of roadway surrounding the HSR section experienced minimal change in the crash rates. The study states its major finding is that with a proper safety analysis during the design, along with removing high risk areas ahead of the implementation, the HSR section will remain at a similar safety level. Another result emphasized was if the safety is below a specific level of crash rates, the safety can be assumed to remain the same after HSR implementation.

One positive result for HSR was for safety to not be negatively impacted by the HSR. This study, based upon empirical data, found that to be true on these specific German freeways. The introduction of this study did indicate that a structural analysis is needed to be completed before implementation to ensure pavement performance, as dictated by the German Highway Capacity Manual (HCM). The inclusion of this caveat in the German HCM, while it does not determine effects of HSR on the shoulder pavement, does display an effort to minimize any negative impact that could have occurred. The freeway design guide for Germany has also changed to a design that includes hard shoulders that can handle HSR and the geometric cross-section can be converted to HSR with minimal to no restriping. This study found HSR did not negatively affect the roadway and indicates that Germany accounts for the pavement effects by analyzing the capacity of the roadway before implementation.

2.3. Operational Experience with Temporary Hard Shoulder Running in Germany [7]

The title of this study suggests it is completely focused on operations but it does provide a simple informative safety analysis. The study was another real world study on HSR already implemented in Germany on Freeway A5 from Friedberg to Bad Homburg and Freeway A3 from Hanau to Frankfurt. The study was completed with loop detector data for the operational analysis and the safety was based upon crash rates. The crash rates in the study were analyzed between Oberstshausen and Offenbach on Freeway A3. The interesting results were that the HSR did not affect the crash rates at all but the crash rates upstream of the HSR region improved noticeably. The data included within the analysis was four years prior to implementation, a year of a temporary installation system, and final implementation into a line control system. The total crash rate, or accident rate with study terminology, remained relatively stable across each year. There is a random spike in one of the years after the full implementation. There was an additional spike during the temporary installation year but that could be expected when a new operational flow is implemented as it alters the drivers' expectations. The study suggests the reduction upstream is due to the reduction in rear-ending crashes that occur when approaching the congestion.

This particular paper was included partially due the additional emphasis on safety but it also mentioned the pavement performance. The reference to pavement performance is minimal as it acknowledges that for the implementation of HSR can be simple especially if the shoulder pavement is able to handle the traffic loading possibly applied due to HSR. This study overall is a simple safety aspect focused example. This study states that HSR does not increase crash rates on the HSR section and improvement on upstream crash rates transpires as oncoming traffic does not encounter a sudden change in traffic flow. This provides positive results for the further implementation HSR.

2.4. Relationships Between Freeway Flow Parameters and Safety and Its Implications for Hard Shoulder Running [8]

This study focused on one of the major ideas being research with this paper: does the benefit of additional capacity from HSR balance the loss of a shoulder? The study collected extensive hourly data for Interstate 70 (I-70) that crosses through City of Denver, Colorado to determine a detailed profile of crash rates across the five year time span used for the study. Utilizing the extensive data the study developed multiple site specific safety performance function (SPF). One specific SPF focused on including density, specifically density multiplied by speed within the I-70 corridor, in the formation to directly link levels of congestion to the crash rates calculated. The SPF followed their expect results of reaching a specific density that the crash rates would increase drastically. Utilizing this site specific SPF the study analyzed a portion of I-70 that had a volume of 1,870 vehicles per hour per lane (vphpl). This four lane segment when utilizing HSR would have an estimated volume of 1,247 vphpl. When comparing the different volumes to the SPF, a substantial decrease in the crash rate from 1.20 accident per million vehicle miles traveled (acc/MVMT) to 0.46 acc/MVMT. The study does acknowledge that this is lower than it more realistically is because of the formation of the SPF. The SPF is formed on the basis of full shoulders on I-70. To account for this difference in roadway structure of no shoulder, the study found the range of crash increase from the removal of full shoulders from the FHWA Crash Modification Factors Clearinghouse to be 20-25%. The estimated crash rate factoring the 25% increase is 0.58 acc/MVMT, still a noticeable decrease from the 1.20 acc/MVMT crash rate beforehand. From the results of their findings, this study believes the benefit of the temporary additional lane would vary depending on the change in total lanes. An example from the study highlighted that a roadway with 1870 vphpl each direction on a two lane roadway, when evenly split, would reduce to 1247 vphpl with the addition of the third HSR lane in each direction. The new density is $2/3^{rd}$ of the original density of 1870 vphpl when converting from four total lanes to six total lanes. The study further elaborates by stating that converting from a two lane roadway to a four lane highway the density of 1870 vphpl drops to 935 vphpl, half of the original higher density. With higher amounts of lanes the reduction of density would diminish as there is a more substantial total volume to distribute across the large amount of total lanes. The reduction in density can result in significant improvements in safety as it will provide safer free flowing network even without the shoulder.

The strength of this paper is connecting the operational aspects to the safety aspects of the roadway and the effects of HSR. This approach is just another example that HSR could possibly be beneficial to the safety of the roadway. The paper does acknowledge that it is a simple approach to analyzing the safety effect of HSR but it accomplished its aim and suggesting HSR removing the shoulder can be balanced by the increased capacity. Overall, the key findings stated within this study is that the fundamentals of traffic flow agree that HSR can be beneficial even with the safety effects.

2.5. Others Studies That Touch Upon Non-Operational HSR Effects

Other studies that mention the non-operational effects but were not included within this paper are summarized below in Table 1. These studies are important but the previous studies provided more descriptive information for this paper. These studies were selected to be included, even as just small summaries, as they were developed either by a federal agency or the study was completed by an agencies where HSR was already implemented.

Table 1. Other Studies Including Non-Operational HSR Effects.

Document Title	Results found within Document
Efficient Use of Highway Capacity Summary [9]	This document was a synthesis of the history and use of HSR. A select few studies, mainly anecdotal, indicating HSR did not negatively impact safety. A National Cooperative Highway Research Program (NCHRP) study, mentioned, found the same no negative impact across the multiple state corridors analyzed for the study [10]
Planning for Active Traffic Management in Virginia: International Best Practices and Implementation Strategies [11]	This study did not produce results but focused on developing a system to analyze the safety effects of HSR in simulation or after implemented. Some factors for simulation included number of stops, lane changes, and changes in speed when meeting congestion. For after implementation, the data focused on more in-depth crash detail data.
Safety Impact of using the Hard Shoulder During Congested Traffic: The Case of a Managed Operation on a French Urban Motorway [12]	This study found that the decreased density when utilizing HSR decreased the total crashes but a significant portion of the reduction moved downstream of the HSR section. The total reduction found by the study as statistically insignificant was roughly a 3% reduction.

3. Conclusions

This paper found a selection of research studies that has an emphasis on non-operational effects of HSR such as towards safety and pavement performance effects. The conclusions below will focus on the findings of the studies discussed in depth. The studies in Table 1, above, will not be the focus of the conclusions below as not enough information was able to be provided within the descriptions to be included.

- HSR was found to reduce overall emissions on a roadway and even counterbalance the negative environmental effects of an incident occur on a roadway.
- HSR has been established through multiple studies to not negatively affect the safety of the roadway and could possibly improve the safety in specific scenarios.
- Pavement performance, while not specifically research, has been acknowledged as an aspect to be aware of when implementing HSR.

This paper aimed to determine the extent of research on the non-operational effects of HSR on the roadway, specifically safety and pavement performance. It was found that for safety and even environmental effects of HSR can be minimal or even beneficial. The pavement performance effects are acknowledged but are not specifically studied though accounted for in some instances of HSR implementation. Strength and weaknesses of non-operations based research are listed below.

- Strength: Non-operations based research has begun to occur as the need to understand HSR further is realized.
- Strength: Safety, the next logical research area, has begun to be analyzed with an in-depth theory based evaluation.
- Strength: Other HSR aspects, such as the environmental impacts, have begun to be analyzed for their positive or negative affects to the roadway network.
- Weakness: Pavement impact of HSR have not been researched even though HSR will not be sustainable if the shoulder is unable to handle the extra loading from the shoulder use during congestion.
- Weakness: The quantity of research on these non-operations based impacts need to be further evaluated.

The main objective of this paper was to determine gaps in non-operations based research for HSR. The major gap in research found is studying the effects of HSR on the pavement which could have a significant effect on HSR. The other overall gap in research is the limited amount of studies focused on non-operations based research.

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